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Phosphorus Analysis of Major Soil Series Samples from the Lake Erie Drainage Basin

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Introduction

Diffuse source tributary loadings have been shown to be a major source of the total P load to Lake Erie (PLUARG, 1978; Coe, 1982), and most of the diffuse load (perhaps as high as 80 percent) is particulate in the form of eroded sediment. The phosphorus reduction strategies developed by the states and provinces in the Great Lakes have as their cornerstone reduction of the diffuse particulate phosphorus load by adoption of conservation tillage. In order to calculate the reductions in particulate P achieved through reductions in soil erosion, it is necessary to know the total P content of the soil being eroded, the enrichment of total P in sediment compared to the uneroded soil, and a delivery ratio which is the fraction of eroded soil which is transported to the point of measurement or impact. These factors are related through the following equations:

$$SWSL = C.A.ER.E.DR$$
$$WSL = SWSL.SWA$$

where SWSL = subwatershed sediment load
C = total phosphorus concentration in soil by soil type
A = area of each soil type in the subwatershed
ER = total phosphorus enrichment ratio
E = average erosion rate from the subwatershed
WSL = watershed sediment load
SWA = subwatershed area
DR = sediment delivery ratio from subwatershed

A subwatershed may be as small as a field or may be on the order of 100 hectares or more depending on the scale resolution required. The enrichment ratio has been shown to be a function of the erosion rate and could, therefore, be replaced with a function that relates ER to E. Delivery ratio has usually been related to drainage area—in this case SWA—and DR could, therefore, be replaced with a function relating SWA to DR. Assuming, then, that detailed soil mapping is available for the watershed such that individual soil types can be identified and their areas calculated, a total P concentration can be assigned to each soil type and the average erosion rate calculated by USLE, CREAMS, ANSWERS, or other erosion models. If a very small scale is used with a model like ANSWERS, then erosion E can be calculated for each mapping unit. However, for watershed management planning, larger areas will probably be used.

Reliable data on total P concentrations by soil type is probably as limiting for solution of the above equations as is the uncertainty in estimation of phosphorus enrichment ratios and sediment delivery ratios. Total P is not a commonly measured parameter in soils since it is not a very useful indicator of plant P availability. On the other hand, farmers routinely have their soils analyzed for "available" phosphorus which is estimated by a number of mild chemical extractants. Nor is the chemical extraction used for crop-available P the same as that which best correlates with algal-available P, a parameter of interest to those trying to predict the response of various P sources to phytoplankton growth in lakes.

Since plant-available P is a commonly measured soil parameter throughout the Great Lakes Basin, an obvious question is whether or not this parameter can be used to estimate total P or algal-available P. The total P content of soil is made up of a number of fractions (Logan, 1982; Nelson and Logan, 1983) including in general order of decreasing solubility: weakly adsorbed, metastable precipitates, strongly adsorbed, organic, precipitates and coprecipitates with iron and aluminum, and apatites. Of these fractions, only the most "labile" are extractable by the reagents used to estimate plant-available P. Since algae are more efficient extractors of P than are crop plants, algal-available P is best correlated with stronger extractants than those used for plant-available P. Even these stronger extractants, however, only remove a fraction of total P in soil or sediment.

For there to be correlations between total P and plant-available P, total P and algal-available P, or between plant-

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and algal-available P, the phosphorus pools represented by these extractants must be in equilibrium or near equilibrium with each other. For the more insoluble inorganic P forms or more resistant organic P, this is not likely; however, considerable exchange can occur between the more labile pools. Soils that have received little P fertilizer would have low percentages of total P in the more labile fractions but these percentages increase with fertilization. Since considerable fertilization of Great Lakes Basin agricultural soils has occurred in the last 40 years, the relationship between total P and plant-available P has increased. Plant- and algal-available P are likely to be more correlated with each other as they both represent the more labile phosphorus pools in soil.

Approach

The approach used in this study was to analyze archived samples of soil series surface horizons that had been previously collected as part of the soil survey program in Ohio. The reason for using these samples rather than current field samples was to ensure the accuracy of classification of the samples by soil series and because with each sample we had access to extensive mapping and characterization data such as particle size analysis and land use, among others. Sample numbers for each series were approximately stratified according to the acreage representation of the series in the Ohio portion of the Lake Erie Basin. One hundred twenty-nine samples were analyzed representing 17 soil series; sample size per series ranged from 38 for Hoytville to one for minor series.

The soils were analyzed for total P, Bray Pl extractable P (plant-available P), and nonapatite inorganic P (NAIP) which is a measure of algal-available P and is estimated by extraction with 0.1 *M* NaOH (Sonsogni et al., 1982). Each sample was analyzed in duplicate and the means reported. Description of the analytical methods are given below.

Analytical Methods

Total P

This method uses concentrated $HClO_4$ for digestion in 100 ml test tubes in a block digestor capable of attaining 200°C. The tubes are scribed accurately at the 50 ml mark. Sample size is 0.1-1.0 g and the sample is digested in 3 ml of acid for 75 min. at 203°C. After cooling, the contents are made to 50 ml with distilled water, shaken, allowed to settle and the solution separated by centrifugation and decantation. Alternatively, the diluted contents after shaking and settling can be decanted and filtered through Whatman No. 42 paper. The digest is neutralized with 5 *M* NaOH and an aliquot analyzed for P colorimetrically by the ascorbic acid-reduced phosphomolybdate method.

NaOH Extractable P

Soil sample (0.1 g) is placed in 100 ml polyethylene centrifuge tube and 50 ml of 0.1 *M* NaOH added. The soil:solution ratio is 500:1. The tubes are shaken for 17 h and then the solution is separated by centrifugation or filtering as described above. If the extracts are dark colored due to high organic matter in the sample, 5 drops of concentrated H_2SO_4 are added to the extract to flocculate the dissolved organic matter; the solution is then recentrifuged or filtered. An aliquot of the extract is analyzed for P colorimetrically by the ascorbic acid-reduced phosphomolybdate procedure.

Bray P1 Extractable P

The method of Olsen and Sommers (1982) is used. Extracted P is analyzed colorimetrically by the ascorbic acid-reduced phosphomolybdate procedure.

Results

The individual results by soil series are given in Table 1 for total P, Bray Pl-P, and NaOH-P, and means, ranges and standard deviations are given in Table 2. Mean values by series for total P varied from 360 to 930 mg/kg with the highest values for the very fine textured soils of the region such as Hoytville, Pewamo, Palding, Latty, and Toledo. Statistical analysis showed that percent clay was the most important variable in predicting total P content. The correlation between total P and percent clay was highly significant ($p = 0.0001$) and the slope was 11.7 mg/kg total P per percent clay. The mean values for total P bracket well the range of 700-750 mg/kg used previously by Logan for calculations of P loads from soil loss estimates (Logan and Adams, 1981).

Bray Pl-P mean values ranged from 13-50 mg/kg and these are somewhat lower than values found in Ohio agricultural soils today. This difference reflects the older age of the samples we analyzed and also because many of them were in pastures or woodlots when they were sampled and probably had not received fertilizer recently. There was a slight trend for higher values with increasing clay content, but Bray Pl-P was not significantly correlated with percent clay.

NaOH-P values ranged from 68 to 178 mg/kg and there was no trend with clay content and no statistically significant relationship between NaOH-P and clay content. The mean values reported here are several fold lower than those reported by Logan et al. (1979) for tributary sediments in Eastern and Western Lake Erie Drainage Basin. This reflects the enrichment of P in sediments compared to the original soil as a result of preferential erosion and transport

Table 1. Total, NaOH-extractable, and Bray PI-extractable phosphorus by soil series for Lake Erie Basin soils of Ohio. Means of two replicate analyses.

Total-P	NaOH-P	Bray PI-P
	mg/kg	
	Bennington (n=2)	
345	60	10.0
395	75	16.9
	Blount (n=21)	
495	148	17.6
681	191	43.4
409	123	11.1
1154	212	59.9
401	43	27.6
509	147	47.4
505	143	30.1
346	63	101.3
485	76	16.8
491	110	35.0
509	89	39.8
348	81	5.4
289	75	31.4
386	44	23.1
460	51	15.6
523	71	14.1
378	91	13.0
421	43	8.5
818	150	65.5
498	60	7.8
780	119	22.8
	Fulton (n=3)	
614	94	12.5
564	95	13.5
686	113	15.5
	Haskins (n=5)	
313	85	55.4
448	139	17.5
339	81	17.4
284	62	12.3
429	72	10.0

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Table 1 (Continued).

Total-P	NaOH-P	Bray Pl-P
	mg/kg	
	Mahoning (n=14)	
426	75	15.3
619	93	24.8
419	86	27.8
673	86	36.3
400	88	19.6
645	78	34.5
661	96	13.1
730	118	20.1
714	128	31.5
480	31	0.0
594	128	26.8
466	100	18.6
870	205	20.0
784	265	43.4
	Nappanee (n=3)	
550	0	10.0
550	150	25.3
716	55	10.6
	Orrville (n=2)	
635	107	25.3
844	117	6.9
	Paulding (n=5)	
1001	118	45.1
1044	125	53.1
735	10	27.5
1045	156	45.8
828	103	24.3
	Pewamo (n=22)	
911	215	67.6
538	42	15.0
1018	139	44.4
836	71	28.3
935	219	36.5
624	28	212.1
1031	103	48.3
1466	661	236.9

Continued

Table 1 (Continued).

Total-P	NaOH-P	Bray PI-P
	mg/kg	
	Pewamo (n=22) (Continued)	
665	48	17.0
940	148	30.5
1040	255	61.8
731	124	18.6
941	191	31.4
676	67	19.4
939	183	64.5
860	128	22.1
704	59	15.5
981	73	35.4
700	103	6.1
1030	104	35.6
1135	208	53.1
828	108	14.1
	Ravenna (n=1)	
766	127	19.6
	Sheffield (n=1)	
555	166	26.5
	Sloan (n=1)	
988	181	37.5
	Toledo (n=8)	
681	102	20.1
775	51	17.6
795	66	47.5
791	27	25.4
93	149	40.0
1064	93	22.3
923	134	81.1
898	174	34.8
	Trumbull (n=2)	
720	102	8.9
946	254	79.8
	Wadsworth (n=1)	
569	119	20.8

Table 2. Total, NaOH-extractable, and Bray P1-extractable phosphorus by soil series for Lake Erie Basin soils of Ohio. Range, means and standard deviations by series.

No. of Obs.	Total-P				NaOH-P				Bray PI-P			
	High	Low	Mean	SD	High	Low	Mean	SD	High	Low	Mean	SD
	mg/kg											
					Bennington							
2	395.0	345.0	370.0	35.4	75.0	60.0	67.5	10.6	16.9	10.0	13.5	4.9
					Blount							
21	1154.0	289.0	518.4	197.4	212.0	43.0	101.4	49.1	101.3	5.4	30.3	23.
					Fulton							
3	686.0	564.0	621.3	61.3	113.0	94.0	100.7	10.7	15.5	12.5	13.8	1.5
					Haskins							
5	448.0	284.0	362.6	72.3	139.0	62.0	87.8	30.0	55.4	10.0	22.5	18.7
					Hoytville							
37	1151.0	493.0	830.5	120.1	163.0	28.0	74.6	32.6	109.3	13.4	37.2	26.4
					Latty							
3	893.0	739.0	840.7	88.1	121.0	39.0	83.3	41.4	35.5	12.4	25.4	11.8
					Mahoning							
14	870.0	400.0	605.8	147.6	265.0	31.0	112.6	58.4	43.4	0.0	23.7	11.0
					Nappanee							
3	716.0	550.0	605.3	95.8	150.0	0.0	68.3	75.9	25.3	10.0	15.3	8.7
					Orrville							
2	844.0	635.0	739.5	147.8	117.0	107.0	112.0	7.1	25.3	6.9	16.1	13.0
					Paulding							
5	1045.0	735.0	930.6	141.2	156.0	10.0	102.4	55.1	53.1	24.3	39.2	12.6
					Pewamo							
22	1466.0	538.0	887.7	205.1	661.0	28.0	149.0	131.1	236.9	6.1	50.7	59.0

(Continued)

Table 2. (Continued)

No. of Obs.	Total-P				NaOH-P				Bray Pl-P			
	High	Low	Mean	SD	High	Low	Mean	SD	High	Low	Mean	SD
	mg/kg											
					Ravenna							
1	766.0	—	—	—	127.0	—	—	—	19.6	—	—	—
					Sheffield							
1	555.0	—	—	—	166.0	—	—	—	26.5	—	—	—
					Sloan							
1	988.0	—	—	—	181.0	—	—	—	37.5	—	—	—
					Toledo							
8	1064.0	681.0	827.5	128.0	174.0	27.0	99.5	50.7	81.1	17.6	36.1	21.0
					Trumbull							
2	946.0	720.0	833.0	159.8	254.0	102.0	178.0	107.5	79.8	8.9	44.4	50.1
					Wadsworth							
1	569.0	—	—	—	119.0	—	—	—	20.8	—	—	—

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Table 3. Relationships between total, NaOH-extractable, and Bray P1 phosphorus for Lake Erie Basin soils of Ohio. For all soil series and by series.

Dependent Variable	Independent Variable	Error d.f.	Intercept (mg/kg)	Slope	R2
		All Soils			
Total	NaOH	129	578.4	1.47	0.220
Total	Bray	129	631.6	3.00	0.190
NaOH	Bray	128	61.1	1.26	0.320
		Blount			
Total	NaOH	19	220.4	2.94	0.530
NaOH	Bray	19	79.3	0.73	0.120
		Fulton			
Total	NaOH	1	105.7	5.12	0.800
NaOH	Bray	1	7.8	6.71	0.920
		Haskins			
Total	NaOH	3	224.4	1.57	0.430
NaOH	Bray	3	85.4	0.11	0.004
		Hoytville			
Total	NaOH	35	634.7	2.61	0.490
NaOH	Bray	34	39.0	1.00	0.660
		Latty			
Total	NaOH	1	675.2	1.99	0.870
NaOH	Bray	1	−5.40	3.49	1.000
		Mahoning			
Total	NaOH	12	407.2	1.76	0.490
NaOH	Bray	12	43.6	2.91	0.300
		Nappanee			
Total	NaOH	1	618.5	−0.19	0.020
NaOH	Bray	1	−58.2	8.27	0.890
		Paulding			
Total	NaOH	3	696.6	2.29	0.800
NaOH	Bray	3	-11.4	2.91	0.440
		Pewamo			
Total	NaOH	20	698.1	1.27	0.660
NaOH	Bray	20	80.7	1.35	0.370
		Toledo			
Total	NaOH	6	792.8	0.35	0.020
NaOH	Bray	6	64.4	0.97	0.160

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